FAIL-SAFE ENGINE COOLING CONTROL ALGORITHM FOR HYBRID ELECTRIC VEHICLE

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to a Hybrid Electric Vehicle (HEV), and specifically to a system and method of allowing an HEV engine to operate without damage after the HEV engine cooling system has been compromised (namely, total loss of coolant).

Discussion of the Prior Art

The need to reduce fossil fuel consumption and emissions in automobiles and other vehicles powered by Internal Combustion Engines (ICEs) is well known. Vehicles powered by electric motors attempt to address these needs. Unfortunately, electric vehicles have limited range and power capabilities. Further, electric vehicles need substantial time to recharge their batteries. An alternative solution is to combine a smaller ICE with an electric traction motor into one vehicle. Such vehicles are typically called Hybrid Electric Vehicles (HEVs). See generally, U.S. Pat. No. 5,343,970 to Severinsky.

The HEV is described in a variety of configurations. Many HEV patents disclose systems where an operator is required to select between electric and internal combustion operation. In other configurations, the electric motor drives one set of wheels and the ICE drives a different set.

Other, more useful, configurations have developed. For example, a Series Hybrid Electric Vehicle (SHEV) configuration is a vehicle with an engine (most typically an ICE) connected to an electric motor called a generator. The generator, in turn, provides electricity to a battery and another motor, called a traction motor. In the SHEV, the traction motor is the sole source of wheel torque. There is no mechanical connection between the engine and the drive wheels. A Parallel Hybrid Electrical Vehicle (PHEV) configuration has an engine (most typically an ICE) and an electric motor that together provide the necessary wheel torque to drive the vehicle. Additionally, in the PHEV configuration, the motor can be used as a generator to charge the battery from the power produced by the ICE.

A Parallel/Series Hybrid Electric Vehicle (PSHEV) has characteristics of both PHEV and SHEV configurations and is typically known as a "powersplit" configuration. In the PSHEV, the ICE is mechanically coupled to two electric motors in a planetary gear-set transaxle. A first electric motor, the generator, is connected to a sun gear, and the ICE is

connected to a carrier. A second electric motor, a traction motor, is connected to a ring (output) gear via additional gearing in a transaxle. Engine torque powers the generator to charge the battery and the resultant torque at the ring gear contributes to the wheel (output shaft) torque. The traction motor is also used to contribute wheel torque and to recover braking energy to charge the battery if a regenerative braking system is used. In this configuration, the generator can selectively provide a reaction torque that may be used to control engine speed. In fact, the engine, generator motor and traction motor can provide a continuous variable speed transmission effect. Further, the HEV presents an opportunity to better control engine idle speed over conventional vehicles by using the generator to control engine speed.

The desirability of combining an ICE with electric motors is clear. There is great potential for reducing vehicle fuel consumption and emissions with no appreciable loss of vehicle performance or drive-ability. Nevertheless, new ways must be developed to optimize the HEV's potential benefits.

One such area of development is in the development of advanced control systems that can allow the HEV to continue operation even after an engine coolant system malfunction. It is generally known that malfunctions of engine cooling systems can cause engine damage from the excessive overheating. Such malfunctions often involve loss of coolant. Coolant loss can

be sudden due to a leak in the cooling system. Alternatively, overheating malfunctions without coolant loss can occur if the coolant circulation system malfunctions such as a failure of a water pump.

Methods of allowing an engine to continue to operate without damage after coolant system failure are known in the prior art and known as "fail-safe cooling." One such prior art fail-safe method alternates fueling and firing cutoffs to the engine cylinders. For example, U.S. Patent No. 5,555,871 to Gopp, et al., describes an engine cylinder head temperature sensor and the control system. When the cylinder head temperature exceeds a threshold, the control system deactivates one or more of the engine's cylinders. The control system rotates the deactivation of the cylinder's spark so that no cylinder is constantly fired. While deactivated, fresh air is drawn through the cylinders and cools the engine.

The prior art also describes alternating fuel flow to deactivate a cylinder bank when a temperature threshold is passed. In this fail-safe mode, the air fuel mixture of the activated cylinder bank is adjusted to limit vehicle speed and extend the operating time. See generally, U.S. Pat. No. 4,473,045 to Bolander, et al.

Various other fail-safe systems exist in the prior art. In U.S. Patent No. 5,094,192 to Seiffert, et al., ignition

slows in response to coolant pump failure. This limits the load and speed of the engine.

Other fail-safe methods to reduce engine heat when the coolant system fails trigger a water pump or cooling fans to cool the engine compartment. U.S. Pat. No. 4,977,862 to Aihara, et al. Similarly, U.S. Pat. No. 5,065,705 to Fujimoto, et al., describes a system based on engine speed that reduces engine power output if it predicts the overheating of the engine.

Although the prior art fail-safe systems are useful when applied to convention ICE vehicles, the HEV can utilize additional methods to reduce engine damage when its coolant system fails. For example, it can limit or even shut down engine operation and provide torque through its traction motor. Further, the HEV provides other design challenges not experienced in the prior art. For example, the prior art fail-safe systems typically apply to a large ICE with six or more cylinders. In smaller ICEs (four cylinder or less) such as those found in an HEV, engine power output, and noise vibration, and harshness (NVH) would be unacceptable using the prior art fail-safe systems.

NVH is objectionable noise, vibration or harshness felt by the vehicle operator or its occupants. NVH can be transmitted by air or structure, and typically manifests itself in the form of vibration felt through the steering

wheel, seat, foot pedals or as a vibrating mirror or loud noise heard at certain engine or road speeds.

Because of the shortcomings of the prior art when applied to an HEV, plus their inability to utilize the advantages provided by the HEV, a new type of HEV fail-safe system is necessary. Unfortunately, no such HEV fail-safe system exists.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide a fail-safe engine cooling control method and system for a hybrid electric vehicle (HEV) when the engine temperature exceeds a predetermined calibratable level such as when a vehicle coolant system fails.

It is a further object of the present invention to provide a fail-safe method and system that reduces engine power output and NVH (torque pulsations), whereby the HEV operating range is greatly increased.

It is a further object of the present invention to provide a fail-safe method and system that reduces maximum engine power output to half its normal operation, whereby acceptable engine temperature, vehicle NVH, and operating range are maintained.

It is a further object of the present invention to provide a fail-safe method and system to halt engine operation, but allow engine operation if necessary, with a fuel cut method to one or more cylinders in an alternating fashion.

It is a further object of the present invention to ensure the HEV does not run in a parallel mode, whereby the generator is not coupled to the engine for production of charge for the battery. This method and system will isolate torque propulsions from the wheels and reduce the NVH.

It is a further object of the present invention to force engine operation at a speed that is optimized for reduced NVH and reduced engine temperature.

It is a further object of the present invention to control the HEV cooling fans to an optimal speed to minimize electrical load while maximizing air circulation, based on HEV speed and engine temperature.

Other objects of the present invention will become more apparent to persons having ordinary skill in the art to which the present invention pertains from the following description taken in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE FIGURES

The foregoing objects, advantages, and features, as well as other objects and advantages, will become apparent with reference to the description and figures below, in which like numerals represent like elements and in which:

Figure 1 illustrates a general hybrid electric vehicle (HEV) configuration.

Figure 2 illustrates a prior art engine coolant system configuration with an electric coolant pump.

Figure 3 illustrates the control strategy of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention relates to Electric Vehicles and, more particularly, Hybrid Electric Vehicles (HEVs). Figure 1 demonstrates just one possible configuration, specifically a Parallel/Series Hybrid Electric Vehicle (powersplit) configuration.

In a basic HEV, a Planetary Gear Set 20 mechanically couples a Carrier Gear 22 to an Engine 24 via a One Way Clutch 26. The Planetary Gear Set 20 also mechanically couples a Sun Gear 28 to a Generator Motor 30 and a Ring (output) Gear 32. The Generator Motor 30 also mechanically links to a Generator Brake 34 and is electrically linked to a Battery 36. A

Traction Motor 38 is mechanically coupled to the Ring Gear 32 of the Planetary Gear Set 20 via a Second Gear Set 40 and is electrically linked to the Battery 36. The Ring Gear 32 of the Planetary Gear Set 20 and the Traction Motor 38 are mechanically coupled to Drive Wheels 42 via an Output Shaft 44.

The Planetary Gear Set 20, splits the Engine 24 output energy into a series path from the Engine 24 to the Generator Motor 30 and a parallel path from the Engine 24 to the Drive Wheels 42. Engine 24 speed can be controlled by varying the split to the series path while maintaining a mechanical connection through the parallel path. The Traction Motor 38 augments the Engine 24 power to the Drive Wheels 42 on the parallel path through the Second Gear Set 40. The Traction Motor 38 also provides the opportunity to use energy directly from the series path, essentially running off power created by the Generator Motor 30, thereby reducing losses associated with converting energy into and out of chemical energy in the Battery 36.

A Vehicle System Controller (VSC) 46 controls many components in this HEV configuration by connecting to each component's controller. The VSC 46 also contains a Powertrain Control Module (PCM). The VSC 46 and the PCM, though housed in the same unit, are actually separate controllers.

The VSC 46 connects to the Engine 24 via a hardwire

interface and Engine Control Unit (ECU) 48. The ECU 48 and the VSC 46, like the PCM, can be based in the same unit, but are actually separate controllers. The VSC 46 also connects to a Battery Control Unit (BCU) 50, and a Transaxle Management Unit (TMU) 52 through a communication network such as a Controller Area Network 54. The BCU 50 connects to the Battery 36 via a hardwire interface. The TMU 52 controls the Generator Motor 30 and Traction Motor 38 via the hardwire interface.

The basic HEV configuration can also have a variety of ways to cool the Engine 24. For purposes of demonstrating the preferred embodiment of the present invention, a prior art cooling system schematic for a conventional vehicle with an electric coolant pump is shown in Figure 2. An Electric Coolant Pump 60 pumps coolant to the Engine 24. As coolant passes through the Engine 24, it absorbs heat, by conduction, created by Engine 24 combustion. Temperature is measured by an Engine Temperature Sensor (ETS) 62 and sent to a Pump Duty Cycle Controller 64 under the control of the VSC 46 as well as the VSC 46. The ETS 62 can be an engine coolant temperature sensor or a cylinder head temperature sensor.

The Electric Coolant Pump 60 speed is controlled in accordance with the signal from the ETS 62. For example, when the Engine 24 temperature is relatively high, the Electric Coolant Pump 60 is on at 100% volumetric flow rate.

The coolant continues through the loop to a Thermostat 66 and a Heater Core 68. The Heater Core 68 rejects heat from the coolant to the passenger compartment based on driver demand such as a dash panel selection for heat and blower speed. The Thermostat 66 controls the amount of coolant allowed through a heat exchanger path of the system.

When the coolant is hot, the Thermostat 66 allows the coolant to proceed to a Heat Exchanger (Radiator) 70 where airflow across the Radiator 70 draws heat out of the coolant. Airflow can be increased across the Radiator 70 by adding at least one Cooling Fan 74 under the control of the VSC. The Cooling Fan 74 not only increases airflow across the Radiator 70, but also across an entire Engine 24 compartment.

From the Radiator 70, the coolant is drawn back to the Electric Coolant Pump 60. When the coolant is cool, the Thermostat 66 allows the coolant to proceed immediately back to the Electric Coolant Pump 60 through a Thermostat Bypass Path 72 path and Heater Core 68 of the system. Since the Heater Core 68 also receives coolant, it acts as a heat exchanger that vents heat from the coolant into the passenger compartment when requested. After leaving the Heater Core 68, the coolant proceeds back to the Electric Coolant Pump 60.

The present invention provides a method and system within the VSC 46 to allow the vehicle to continue operation when its coolant system has failed. One method and system in this

strategy alternates fueling and firing cylinders of the Engine 24 in a fail-safe cooling mode. This method and system result in the Engine 24 effectively producing half its normal power output and additional noise vibration and harshness (NVH) due to the additional time between firing events in this Failure Mode Effects Management (FMEM) mode. Further, in the HEV, the Engine 24 is smaller than in conventional vehicles and Engine 24 operation is not as closely tied to vehicle operation. An HEV's Engine 24 speed can be independent of vehicle speed, and Engine 24 NVH can be isolated from the Drive Wheels 42. The present invention allows the VSC 46 to manage Engine 24 operation to maintain acceptable Engine 24 temperatures, vehicle NVH, and extended operating range.

The control system and method of the present invention is illustrated by the flow diagram of Figure 3. The VSC 46 monitors Engine 24 temperature from the ETS 62 at Step 80. At Step 82, the VSC 46 determines if the Engine 24 temperature is too high. If the Engine 24 temperature is too high, as defined by a predetermined calibratable threshold, the VSC 46 commands the Failure Mode Effects Management (FMEM) 84 mode. This threshold would be set where it is likely that the vehicle coolant system has malfunctioned, or for whatever reason, the Engine 24 is at a sufficiently high temperature where damage could result if it continues to operate normally.

In the FMEM 84 mode of operation, the Algorithm checks to see if the Engine 24 is needed to be operating at Step 86. Engine 24 operation may be required due to, for example, driver demand, battery state of charge, air/conditioning requests. If Engine 24 operation is not required, the VSC will force the Engine 24 off at Step 88. If Engine 24 operation is required, the VSC restricts the system from being in a parallel mode (i.e., ensure that the Generator Brake 34 is not applied) at Step 90. This will isolate torque pulsations from the wheels, thus reducing the operator perceived NVH.

Next, at Step 92, fuel is cut to one or more of the Engine's 24 cylinders in an alternating fashion. This controls the Engine 24 temperature by allowing alternating cylinders to cool because combustion is not occurring and cool air is passed through when there is no fuel to that cylinder.

Next, at Step 94, the Engine 24 is forced to operate at the predetermined calibratable speed that optimizes NVH and Engine 24 temperature.

Next, at Step 96, the speed of the Cooling Fans 74 is controlled in accordance with the signal from the VSC 46. For example, when the Engine 24 temperature is relatively high, the Cooling Fans 74 operate at 100% speed to force air across not only the Heat Exchanger 70, but also directly over the Engine 24. Nevertheless, the VSC controls the Cooling Fan 74 speed to minimize electrical load and maximize air circulation based on vehicle speed and Engine 24 temperature.

The present invention, as described above, is designed to allow the VSC 46 to manage the vehicle operation to maintain acceptable Engine 24 temperature, minimize vehicle NVH, and greatly extend vehicle operating range in the event of failure in the vehicle cooling system.

The above-described embodiment of the invention is provided purely for purposes of example. Many other variations, modifications, and applications of the invention may be made.